Heavy quarkonia production in relativistic d+A and A+A collisions at RHIC, measured by the PHENIX experiment

Hugo Pereira Da Costa, for the PHENIX collaboration
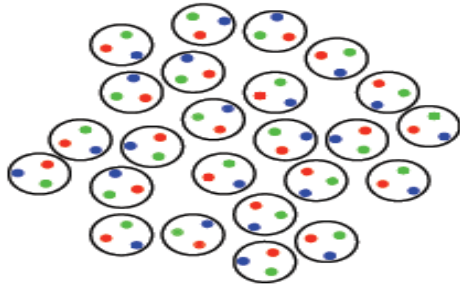
CEA Saclay, LANL

Rencontres de Moriond – March 15, 2010
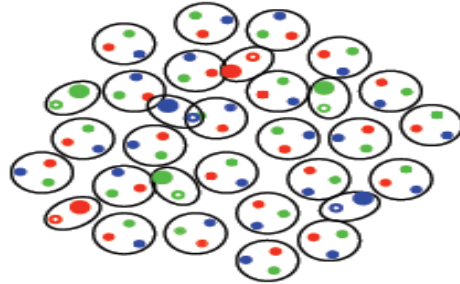
Outline

- Brief introduction on QGP in Heavy Ion collisions

- Heavy quarkonia production in HI collisions

- Selected J/ψ results in dA and AA collisions

- Selected Υ results in dA and AA collisions
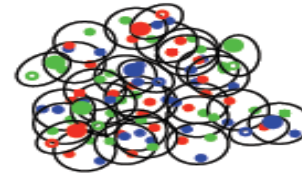
Qualitatively:

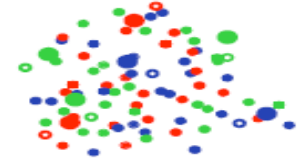
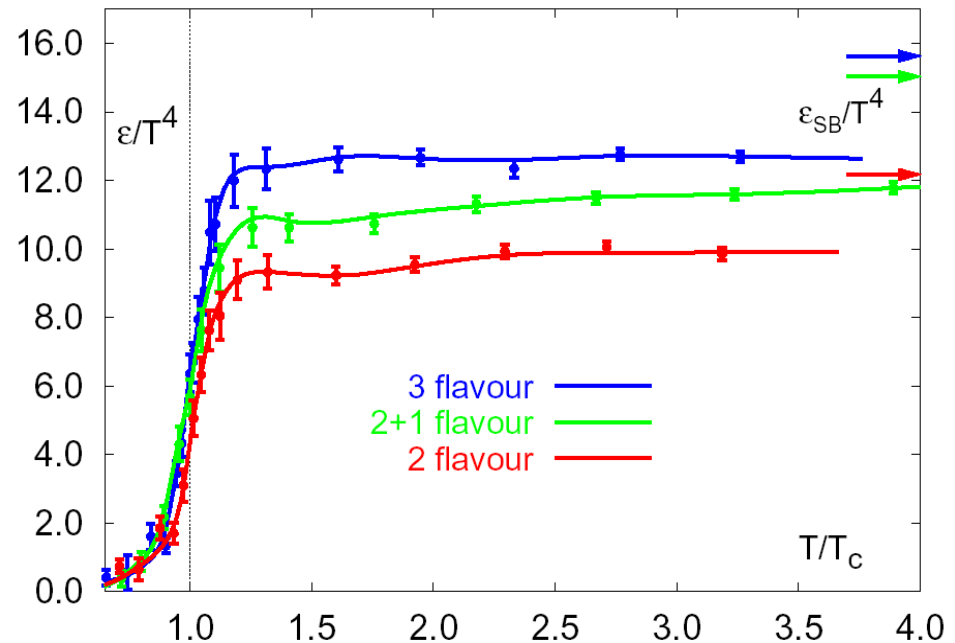Normal nuclear matter   Heating   Compression   Deconfinement

Lattice QCD calculations:

Number of degrees of freedom in nuclear matter vs Temperature

Exhibits a critical temperature T_c above which quarks and gluons are the correct degrees of freedom that describe the medium


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Heavy quarkonia in HI collisions (1)

Heavy quarkonia are good candidates to probe the QGP in heavy ion collisions because:

- they have large masses and are (dominantly) produced at the early stage of the collision, via hard-scattering of gluons.

	mass	radius
J/ψ	3.1 GeV	0.50 fm
ϒ	9.5 GeV	0.28 fm

- they are strongly bound (small radius) and weakly coupled to light mesons.

Sensitive to the formation of a quark gluon plasma via color screening:

Color Screening
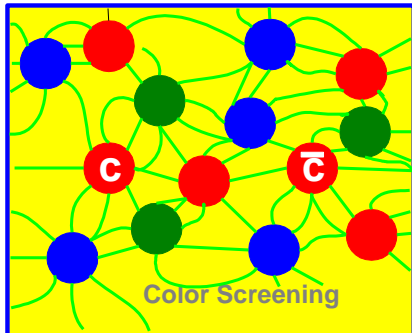
State	J/ψ	ϒ
T_{dis}	1.2 T_c	2 T_c

T_c: QGP formation temperature
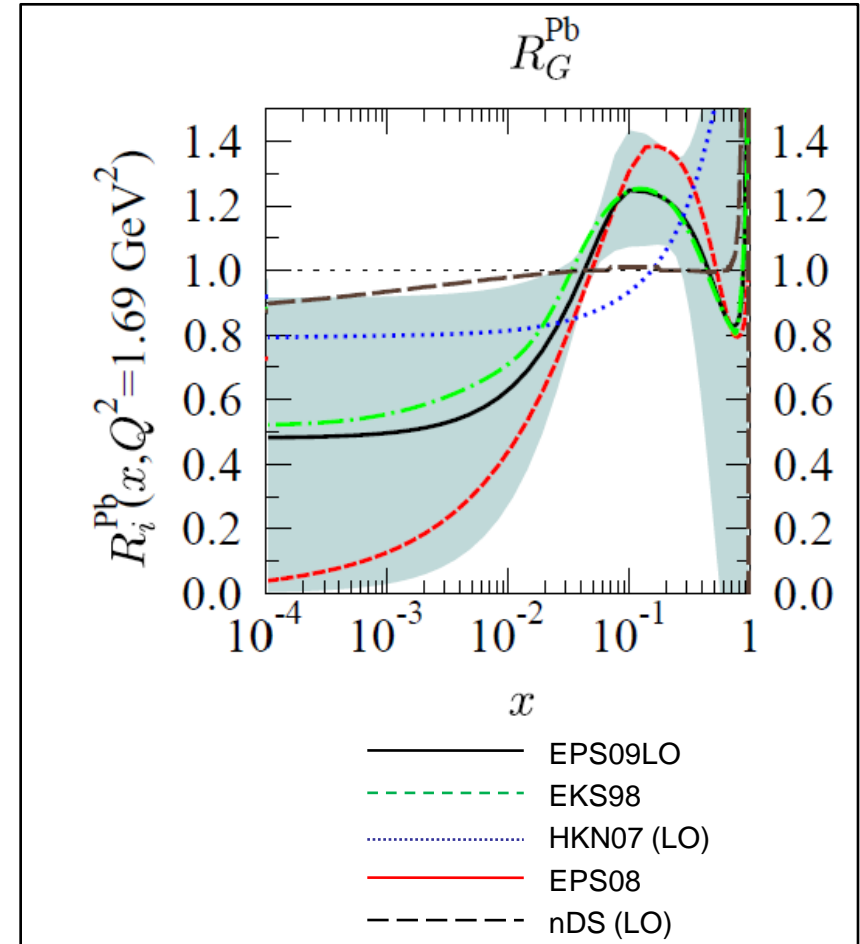T_{dis}: quarkonia dissociation temperature

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Heavy quarkonia in HI collisions (2)

Cold nuclear matter effects:
Modifications of heavy quarkonia production in absence of a QGP

- Modification of the parton distribution functions (pdf) in nuclei

- Dissociation by surrounding hadrons: breakup cross-section $\sigma_{breakup}$

- Initial state energy loss

- Cronin effect

- Other mechanisms (gluon saturation/CGC)

So far, mainly the first two effects (pdf modifications and $\sigma_{breakup}$) have been addressed quantitatively
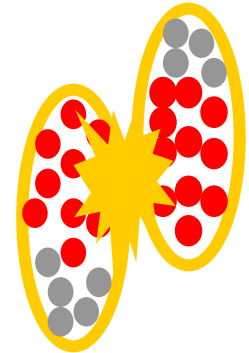

R_G^{Pb}

EPS09LO
EKS98
HKN07 (LO)
EPS08
nDS (LO)

Collision characterization:

Centrality is related to the distance between the center of colliding nuclei (impact parameter b)

Central collisions: small b
Peripheral collisions: large b

N_{part} is the number of nucleons participating to the HI collision
N_{coll} is the number of binary (pp) collisions in one HI collision
Both increase from peripheral to central collisions

Collision	N_{part}	N_{coll}
d+Au (all centralities)		7.6 ± 0.3
Au+Au (all centralities)	109 ± 4	258 ± 25
Au+Au (10% most central)	325 ± 3	955 ± 94

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Tools to study heavy ion collisions (2)

Particle production characterization:

$$R_{AA} = \frac{\text{yield in AA (or dA)}}{N_{coll}. \text{ yield in pp}}$$

Nuclear modification factor to compare p+p to d+A or A+A

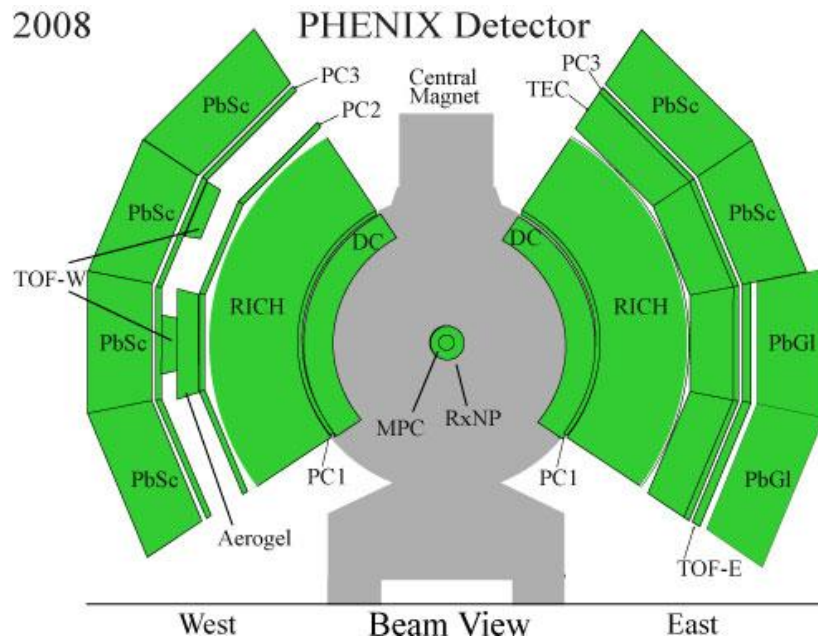$$R_{CP}^{0-20\%} = \frac{N_{inv}^{0-20\%} \Big/ \left\langle N_{coll}^{0-20\%} \right\rangle}{N_{inv}^{60-88\%} \Big/ \left\langle N_{coll}^{60-88\%} \right\rangle}$$

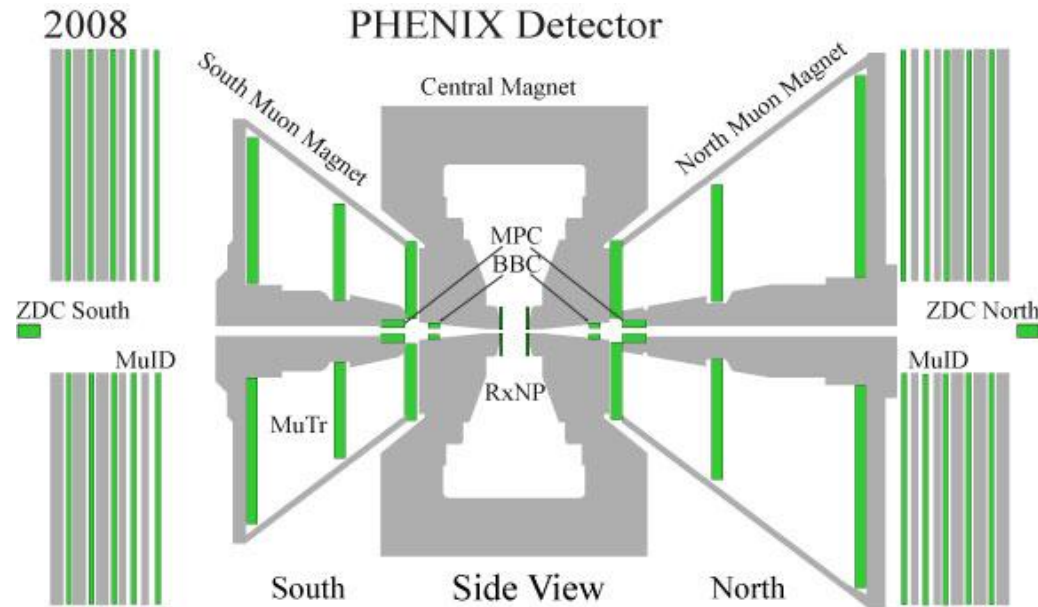Central to peripheral ratio in d+A or A+A (when p+p reference is not available)

For *hard* processes and if everything in AA behaves like in pp, $R_{AA} = R_{cp} = 1$

Heavy quarkonia measurements in PHENIX

Mid rapidity: **J/ψ,**Υ**→ e⁺e⁻**
|η|<0.35, ΔΦ= 2 x π/2, p>0.2 GeV/c

Forward rapidity: **J/ψ,**Υ**→ μ⁺μ⁻**
1.2<|η|<2.2, ΔΦ=2π, p>2 GeV/c

- Measure quarkonia production in p+p for reference (see talk by D. Jouan)
- Measure in d+A collisions to evaluate Cold Nuclear Matter effects and extrapolate to A+A
- Measure additional effects in A+A to evaluate QGP effects

J/ψ production in d+A and A+A at $\sqrt{s_{NN}}$ = 200 GeV
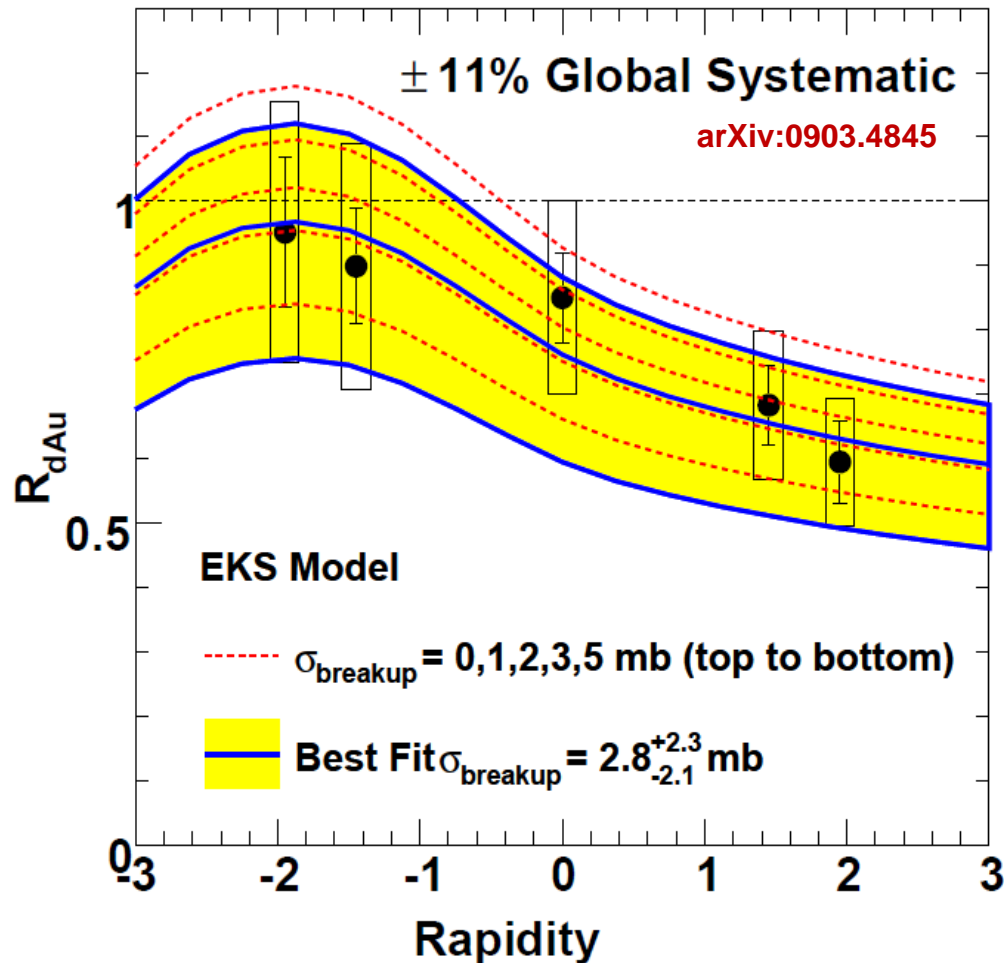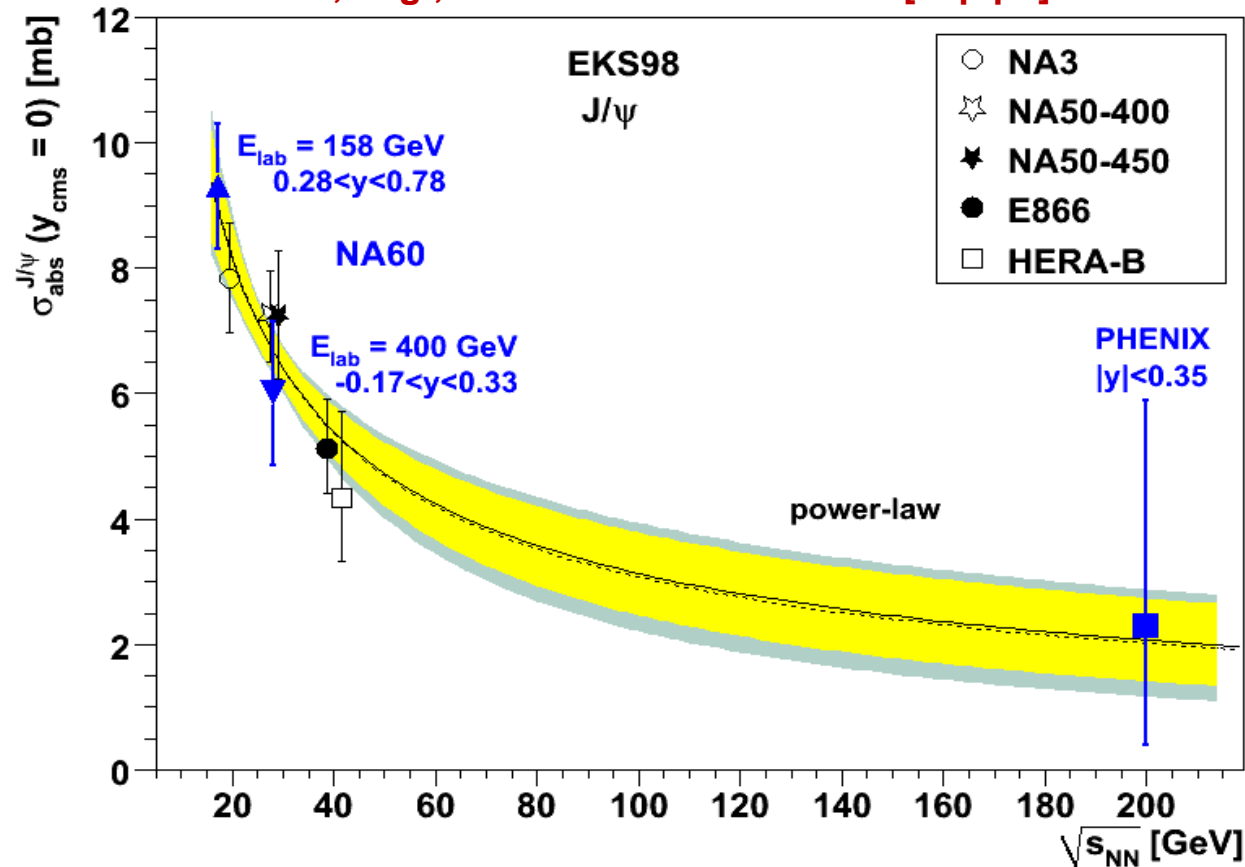
y<0: Au going side. Large x in Au nuclei
y>0: d going side. Small x in Au nuclei,
where shadowing is expected

Shadowing models are used together with $\sigma_{breakup}$ from 0 to 5 mb.
Fit to the data gives (here) $\sigma_{breakup} = 2.8\,^{+2.3}_{-2.1}$ mb
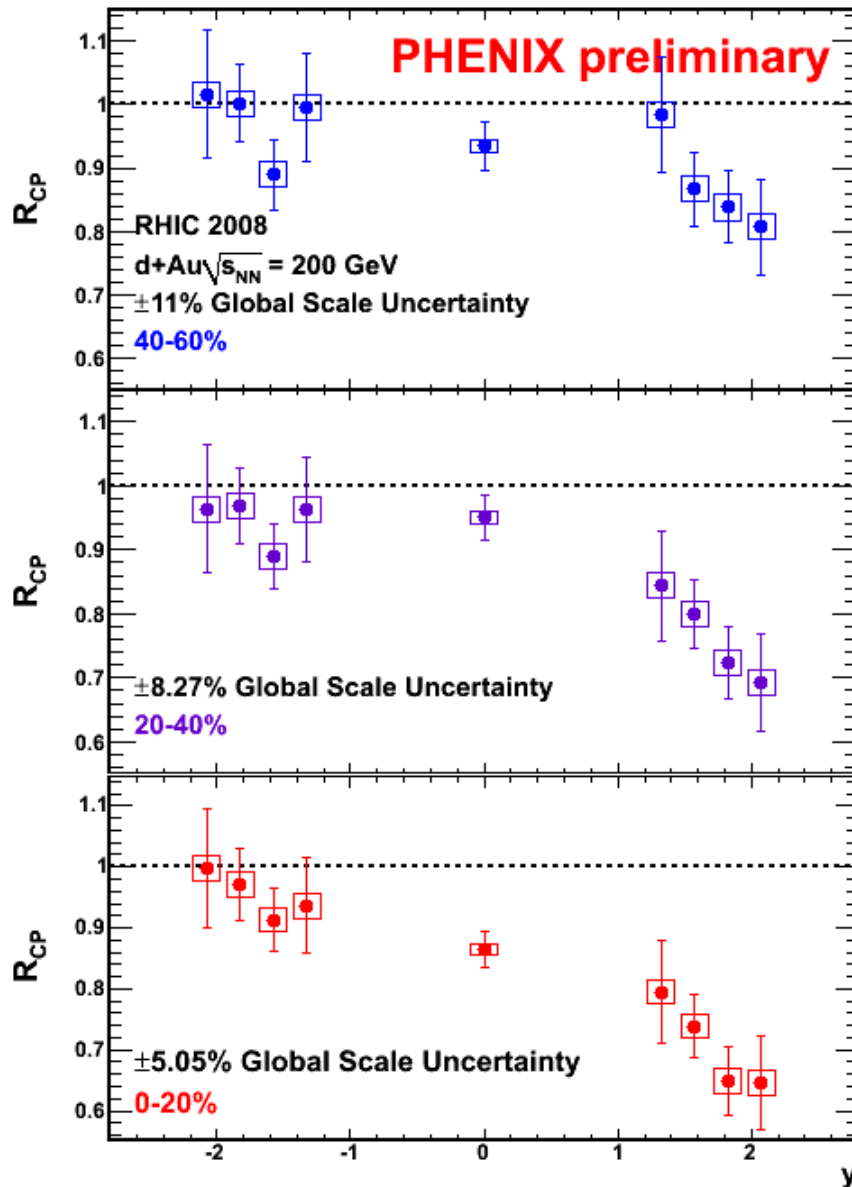
Lourenco, Vogt, Woehri - arXiv:0901.3054 [hep-ph]

Putting $\sigma_{breakup}$ as a function of $\sqrt{s}$ and comparing to other experiments shows some sort of global trend, yet to be explained theoretically.

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Preliminary R_cp (2008 data) vs rapidity

2008 d+Au data sample = ~40 times more statistics than 2003 published results.

Enough statistics to provide 4 different centrality bins and 9 rapidity bins.
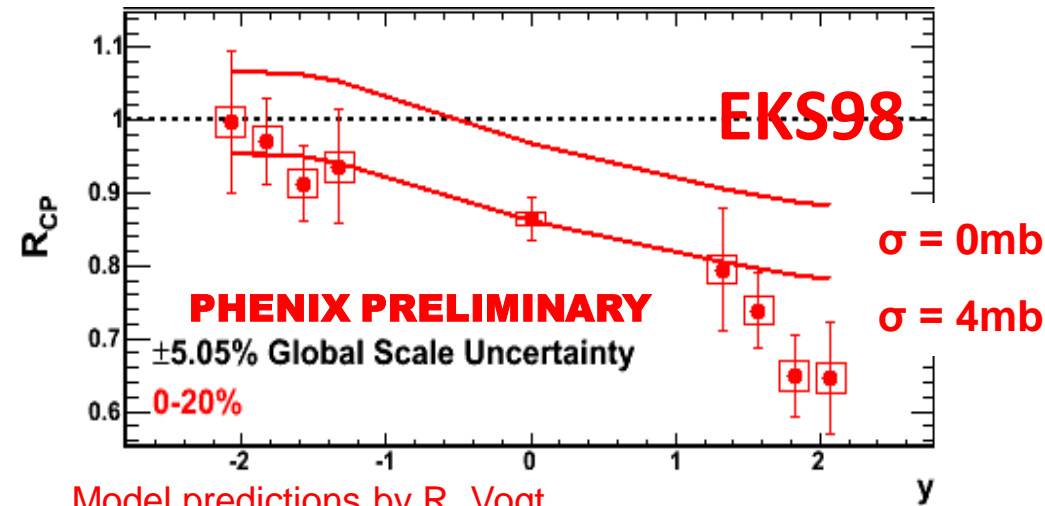
$$R_{CP}^{0-20\%} = \frac{N_{inv}^{0-20\%} \big/ \left\langle N_{coll}^{0-20\%} \right\rangle}{N_{inv}^{60-88\%} \big/ \left\langle N_{coll}^{60-88\%} \right\rangle}$$

Systematic errors largely cancel in R_cp.

R_cp ~1 at negative rapidity
R_cp < 1 and decreases with centrality at positive rapidity

# Effective break-up cross-section vs rapidity

EKS98

σ = 0mb

σ = 4mb

PHENIX PRELIMINARY

±5.05% Global Scale Uncertainty

0-20%

Model predictions by R. Vogt

- Obviously, shadowing + fixed $\sigma_{breakup}$ don't match the observed rapidity dependency

- Use d+Au data to extract <u>effective</u> breakup cross section as a function of rapidity to parameterize all the effects that shadowing is missing

- Same trend observed at mid and forward rapidity by E866 and HERA-B

Lourenco, Vogt, Woehri arXiv:0901.3054

EKS98

PHENIX sys$_{glob}$ +5.0 -4.1 mb

E866

HERA-B

arxiv:0801.0220

peripheral ⟶ central
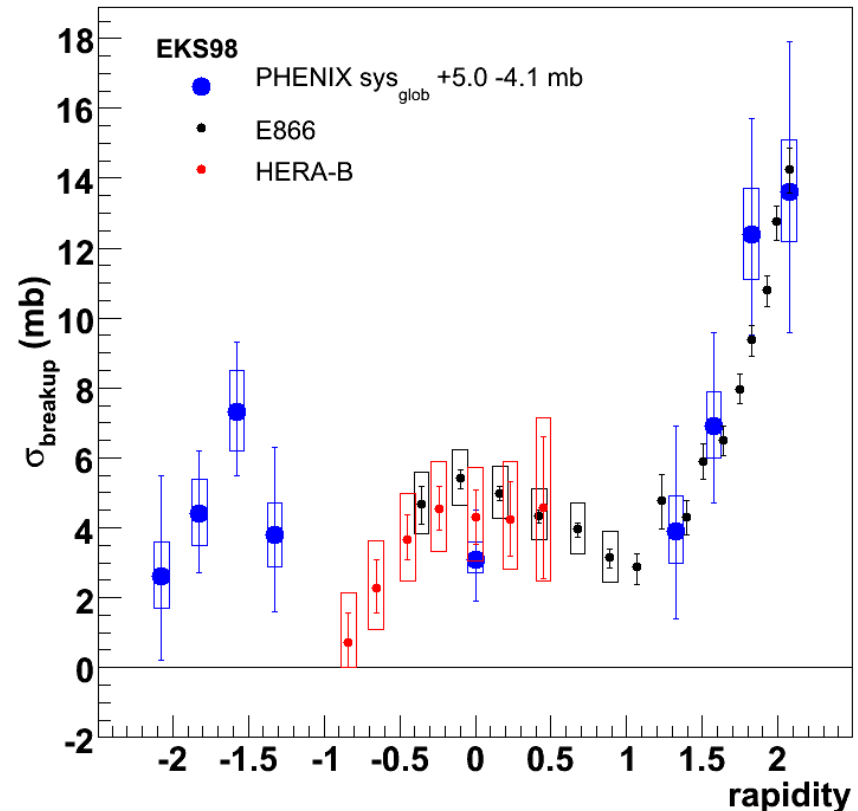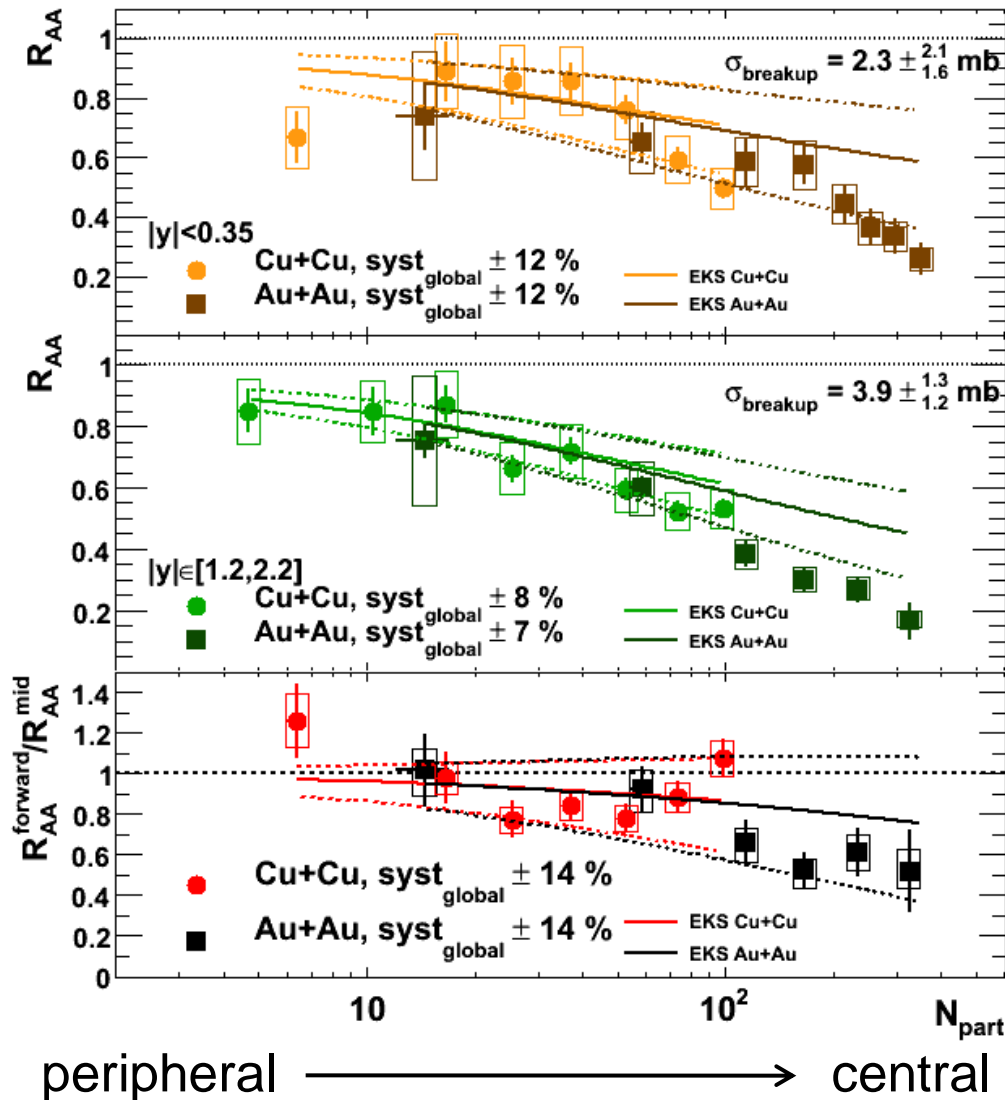
Data are from 2005 Cu-Cu and 2004 Au-Au. Lines are cold nuclear matter effects extrapolated from 2003 d-Au data

Cu-Cu and Au-Au ratios match well where they overlap.
In Au+Au the suppression is larger than expected from CNM

There is more suppression at forward rapidity than at mid-rapidity, although the difference might be absorbed by CNM

Calculations by A. D. Frawley (CATHIE, INT workshop 2009) using rapidity dependent break-up cross-section and errors estimated from 2008 data
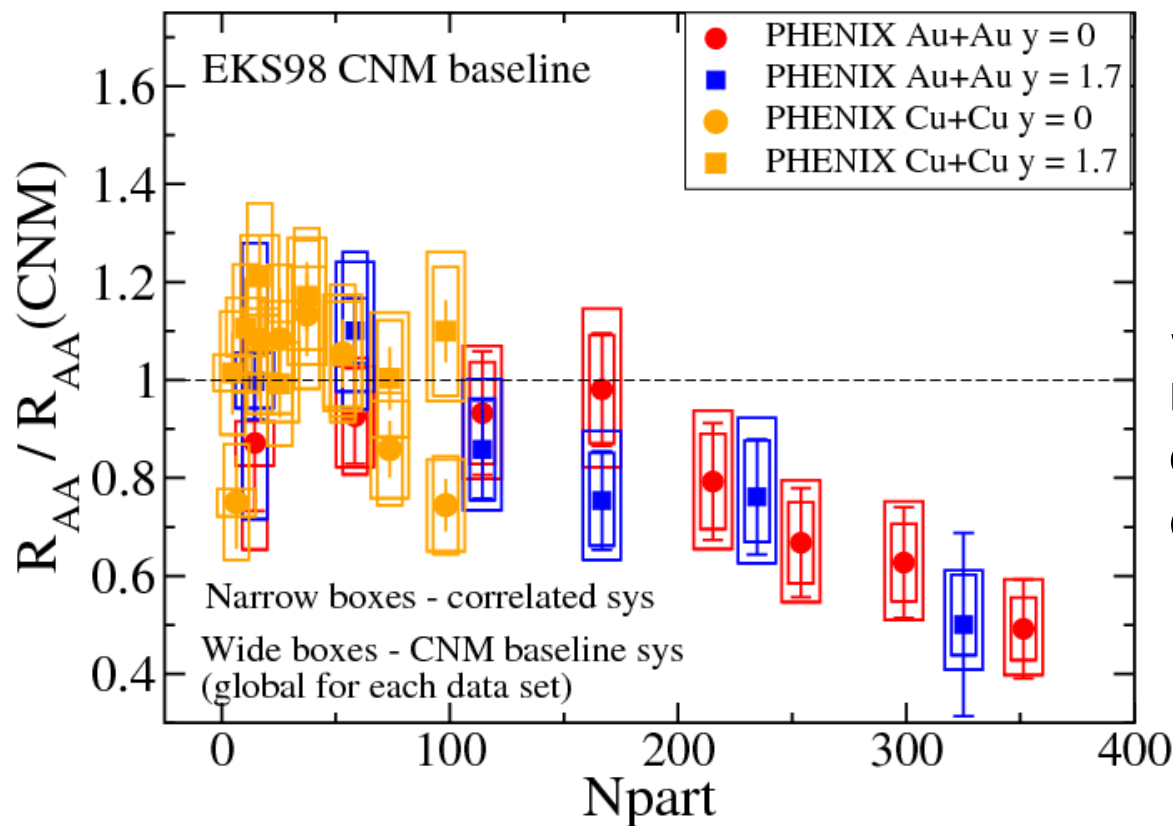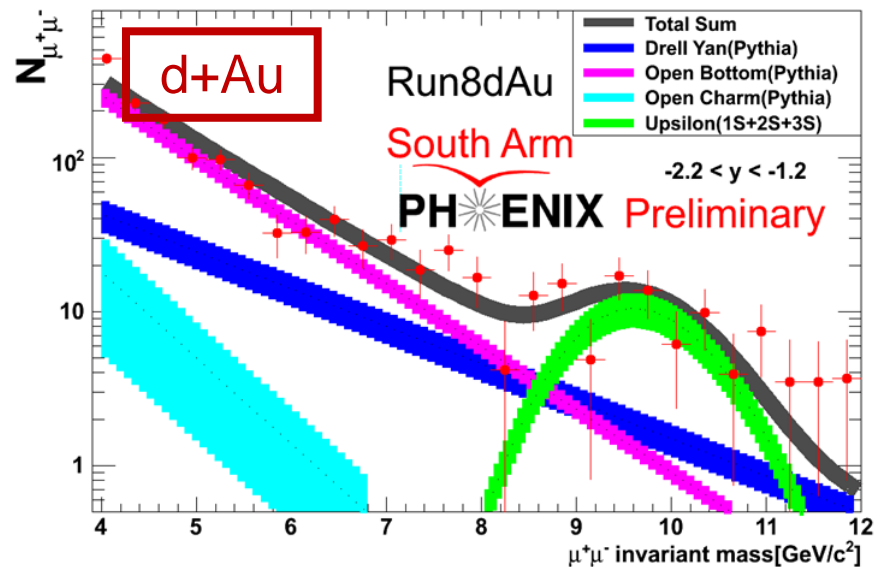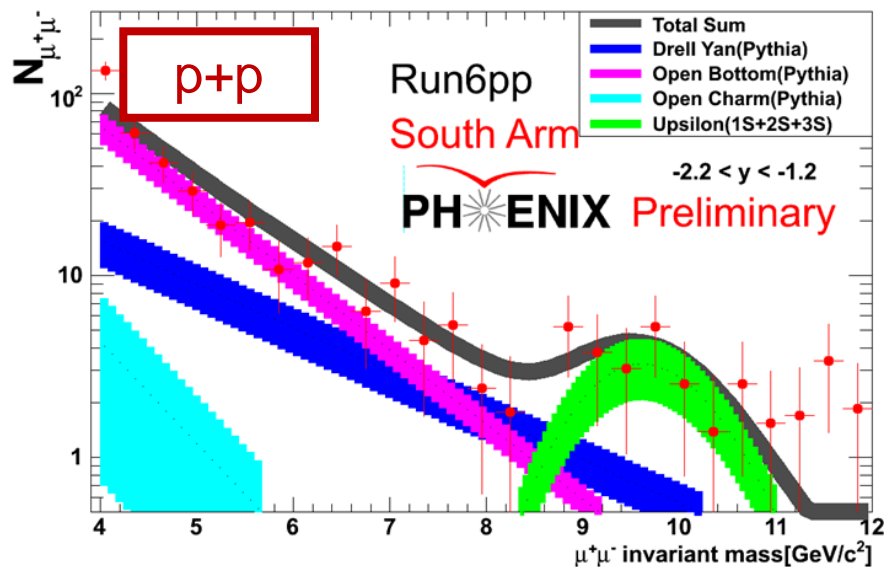

Differences between mid and forward rapidity measurement is washed out.

Suppression beyond cold nuclear matter effects is observed, consistent with de-confinement

Υ production in d+A and A+A at $\sqrt{s_{NN}}$ = 200 GeV

ϒ at forward rapidity in p+p and d+Au

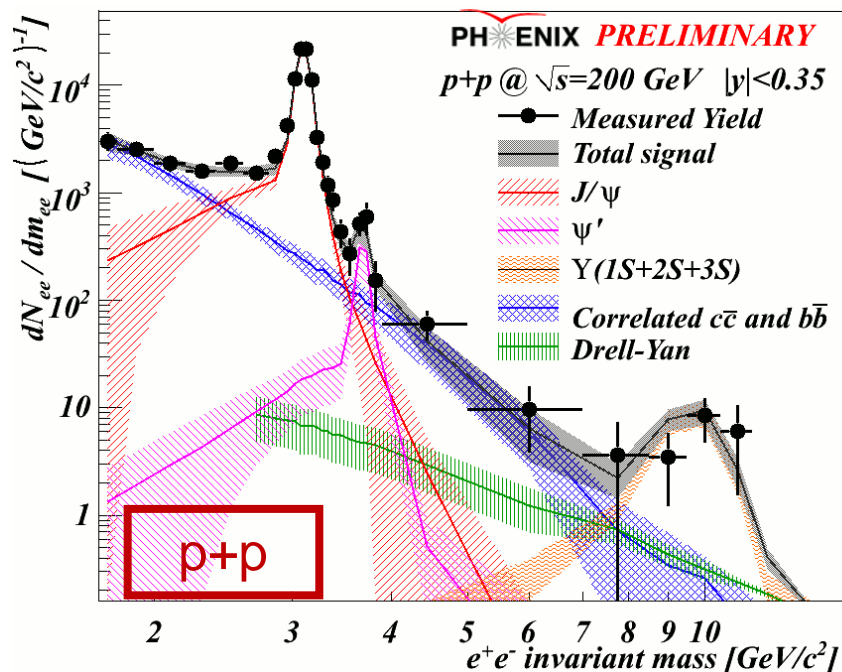First ϒ measurement at forward rapidity (1.2<|y|<2.2) in d+Au collisions

$R_{dAu} = 0.84\pm0.34(\text{stat.})\pm0.20(\text{sys.})$, y [-2.2, -1.2]

$R_{dAu} = 0.53\pm0.20(\text{stat.})\pm0.16(\text{sys.})$, y [1.2, 2.2]

No measurement available (yet) at mid-rapidity
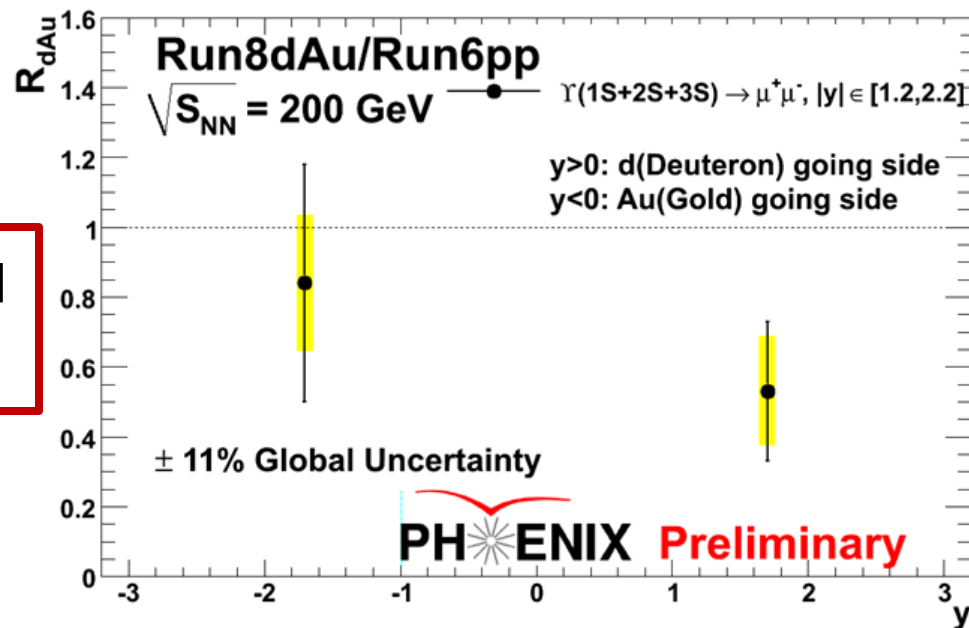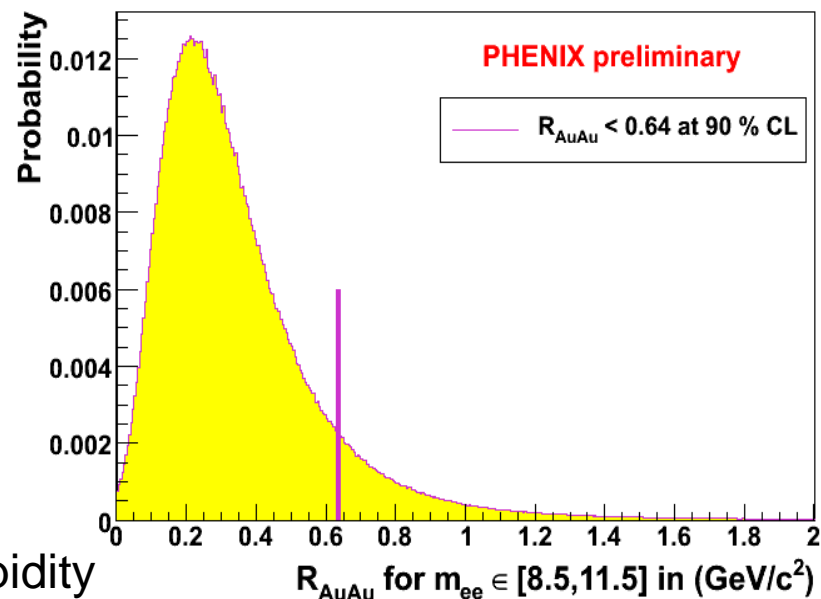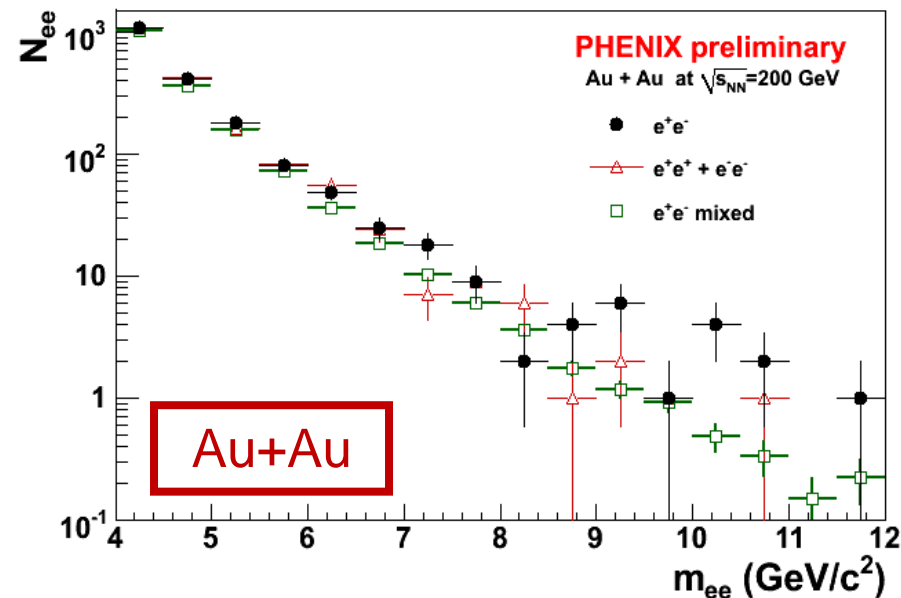
High mass di-lepton R$_{AA}$ in Au+Au

PH✷ENIX *PRELIMINARY*

p+p @ √s=200 GeV |y|<0.35

- ● *Measured Yield*
- *Total signal*
- *J/ψ*
- *ψ'*
- *Υ(1S+2S+3S)*
- *Correlated cc̄ and bb̄*
- *Drell-Yan*

p+p

dN_{ee}/dm_{ee} [(GeV/c²)⁻¹]

e^+e^- invariant mass [GeV/c²]

N_{ee}

PHENIX preliminary
Au + Au at √s$_{NN}$=200 GeV

- ● e^+e^-
- △ $e^+e^+ + e^-e^-$
- □ e^+e^- mixed

Au+Au

m_{ee} (GeV/c²)

Excess over combinatorial background at high mass (m>8GeV/c²) attributed to
- Upsilons
- Open beauty
- Drell-Yan

High mass di-lepton R$_{AA}$:

R$_{AuAu}$ [8.5,11.5] < 0.64 at 90% C.L.

No measurement available (yet) at forward rapidity

Probability

PHENIX preliminary

R$_{AuAu}$ < 0.64 at 90 % CL

R$_{AuAu}$ for m_{ee} ∈ [8.5,11.5] in (GeV/c²)

Conclusion

- J/ψ have been measured extensively at RHIC (PHENIX) in p+p d+Au and Au+Au collisions. Early results (2003-2005) are being extended using higher statistics data sets (2006-2010).

- A first look at 2008 d+Au data show that Cold Nuclear Matter effects are not well understood in terms of shadowing and break-up cross-sections, notably as a function of rapidity. Need more inputs from theory, more observables (notably p_T dependency), more systems (d+Cu ?)

- in Au+Au a suppression is observed beyond the extrapolated CNM, consistent (notably) with de-confinement. There is ~4 times more statistics available with 2007 data, and about the same using 2010 data.

- Some early Υ measurements are available in p+p, d+Au (forward rapidity) and Au+Au (mid-rapidity), and show a pattern qualitatively similar to the one of the J/ψ.